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Bell's theorem and Bohr's principle that the measurement must be classical

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In a recent paper Karl Hess and Walter Philipp claim that hidden local variables cannot be ruled out. We argue that their claim is only valid if one gives up Bohr's principle that the measuring instruments must be classical, and this principle belongs to the foundations of scientific knowledge: Therefore, nonlocal influences can be considered demonstrated.

Bell's theorem [1] states that certain mathematical inequalities ("Bell's inequalities") can be considered a criterion to distinguish between Einstein's local realism [2] and Quantum Mechanics: Local realistic theories satisfy the inequalities, whereas Quantum Mechanics violates them. Experiments conducted in the last two decades demonstrate such a violation and the obtained results are in agreement with the quantum mechanical predictions [3]. This fact has led to the today widespread conviction that in nature there are nonlocal influences acting faster than light [1], even though we cannot use such "Bell influences" for faster than light communication [4].

Nevertheless, Karl Hess and Walter Philipp have recently argued that Bell theorem's proof is flawed. They propose a new local model using so-called time-like correlated parameters, and claim to prove that their extended space of local hidden variables does permit derivation of the quantum predictions and is consistent with all known experiments [5]. The argument has been referred to as "exorcising Einstein's spooks" [6].

In the following we first summarize the Hess-Philipp argument, and then show that it should be considered an invitation to take seriously Bohr's distinction between "quantum object" and "classical measuring instrument" [7], rather than an "exorcism" of nonlocal influences.

The line of the Hess-Philipp argument is the following:

In his proof John Bell introduces an asymmetry in describing the spin properties of the particles and the properties of the measuring equipment. The particle's properties are described by large sets Λ of parameters. By contrast, the measurement apparatus is described by a vector of the Euclidean space (the settings), thus assuming in fact Bohr's postulate that the measurement must be classical [7]. However the measurement apparatus must itself in some form contain particles that, if one wants to be self consistent, also need to be described by large sets of parameters that are related to the settings.

Suppose the physicist at the analyzing station A chooses randomly the setting **a** for his measuring instrument, and the physicist at the station B chooses randomly the setting **b** for his one. The settings **a** and **b** are obviously uncorrelated. However, Hess and Philipp assume that the outcomes at each station are not determined by the source Λ (hidden) variables *and* the settings **a** and **b**, but by the Λ (hidden) variables *and* certain (hidden) parameters $a_1, ...a_N$ (related to the setting **a**) in station A, and $b_1, ...b_N$ (related to the setting **b**)in station B. Moreover, they assume that the parameters $a_1, ...a_N$ are time-like correlated with the parameters $b_1, ...b_N$, the same way as the times indicated by a computer clock in New-York are time-like correlated with those indicated by another clock in Geneva. Under these assumptions the model clearly becomes a local realistic description.

The last stone in the argument consists in showing that such a local model permits (applying some involved mathematics) to derive the correlations between the outcomes at A and B predicted by Quantum Mechanics.

Actually the mathematical model is more general than described above, and does not only encompass parameter sets that can be labeled with the natural numbers. Nevertheless this is not relevant for our discussion below. Note also that by setting in motion the clock in Geneva one additionally introduces a Lorentz transformation, but this does not break the times correlations between the clocks. Therefore, experiments with moving apparatuses [8, 9, 11] would not escape the Hess-Philipp argument either, providing it holds.

In summary, the main assumption of Hess and Philipp is that choosing at random the settings **a** and **b** at the arrival of the particles into the stations does not ensure at all that the space like separated measurements that determine the outcomes at A and B are uncorrelated; they still may have time-related correlations like two setting dependent clocks. But, as they themselves acknowledge, this assumption is only valid if one gives up Bohr's principle that the measurement is classical [7].

So, strictly speaking, what Hess and Philipp really show is that Bohr's distinction between "quantum object" and "classical measuring instruments" [7] is a basic assumption in Bell's proof, so that if one renounces to it, the proof fails, as it fails if one questions that the physicist is capable of performing free-willed choices. This clearly means also that after John Bell's proof in 1964 a huge number of physicists have taken Bohr's principle for the most obvious thing, from those who have established versions of Bell's theorem and/or performed Bell experiments, to those who have proposed local realistic models (other than the Hess-Philipp's one) to explain the results of Bell's experiments.

That so many distinguished physicists (as well localists as nonlocalists) have so easily overlooked that Bell's proof bases on Bohr's principle is a sign that this principle is somehow much more natural than one uses to declare. Indeed that physics, also quantum physics and even all scientific knowledge, begins with classical observations and ends with classical observations can hardly be denied. At the beginning we introduce classical observable properties (time, length, mass, direction, charge, etc.) we can freely vary acting upon. And at the end we register classical observable events: the particle reaches one detector or the other. Only thereafter, we conclude on quantum (classically inexplicable) behavior: observing for instance interferences, we deduce that a particle which can reach the detectors by two alternative paths produces its outcome taking account at once of information concerning both paths. Therefore, the hidden Λ variables have to be defined with relation to the properties we can freely control, i.e. the settings of the measuring instruments.

This is especially clear in Bell experiments using Franson-type interferometers exhibiting a long path and a short one [11]. Here the settings are the lengths l and s of the long respectively short paths, and more precisely the phase-length differences $\delta = l - s$ determining the phase parameters. Suppose you would like to build a local hidden variables theory to explain these experiments. The Λ programs, presumed to be hidden in the particles when they leave the source, cannot be characterized otherwise that with relation to the path-length's differences we set. These programs would consist in strings of the form $\{\delta_1+, \delta_2-, \delta_3+, \delta_4-, ...\}$ containing *all* the possible path-length's differences δ_i the physicists can choose, and the particles would meet when they travel the interferometer, each δ_i having assigned either value $+$ (the particle will undergo transmission at the monitored beam-splitter) or $-$ (the particle will undergo reflection at the monitored beam-splitter). If the programs are so defined, then Bell's theorem holds.

This view of things leads to the conclusion that in the Hess-Philipp model there is no measurement at all, for the relevant variables $a_1....a_N$ and $b_1...b_N$ actually escape the physicist's control.

To finish our discussion we would like to stress two points:

1. If one accepts Bohr's principle and defines the hidden variables with relation to the possible setting choices the physicists can make at the measuring stations, then any hidden variable model rests on the assumption that the particle carries a program containing all possible settings, all possible physicists of all possible times may choose. This is for my taste a monstrous idea far more difficult to swallow than the quantum mechanical assumption, that is, each particle decides about the outcome in arriving at the measuring apparatus though taking account of nonlocal information. In this sense the Hess-Philipp paper helps us to look at Nonlocality as something natural, even without having to wait for violation of Bell's inequalities or other locality criteria.

2. John Bell immensely contributed to increase our interest for two quantum mechanical questions: Nonlocality and Measurement. Regarding Nonlocality he was keen to know whether it is possible to harmonize a time ordered causal description with Einstein's relativity. In order to decide this question we have proposed experiments with moving beam-splitters [8, 10]. This experiments have recently been done [11] demonstrating a new astonishing feature of quantum correlations: they escape description in terms of "before" and "after" by means of any set of real clocks, are brought about without relation to any real timing; there is no real time ordering behind quantum causality [12]. This means that at the fundamental level it is impossible to unify Quantum Mechanics and Relativity, though this has no observable consequence [12]. In this sense one of the quantum conundrums Bell mainly bother about has been solved. Regarding Measurement Bell was irritated by Bohr's division of the world in classical and quantum, which he considered fuzzy and unworthy of a precise theory [13]. Ironically, it now appears that if one gets rid of this division one gets rid of Bell's theorem too, and also any physics, if we might say. So, the sound and cheapest solution would rather consist in maintaining both, Bohr's principle and Nonlocality. Admittedly, the question of where we draw the line between quantum and classical or, in Wheeler's wording, when a process of amplification becomes irreversible and produces a registered phenomenon (i.e. when does a detector actually click) [14], remains a mystery still to elucidate.

In conclusion, the Hess-Philipp's paper doesn't invalidate the proofs of nonlocal influences but invite us to reflect more in depth about Bohr's principle. Experiments with space-like apparatuses in motion seem to have completed the characterization of quantum Nonlocality. Apparently, the interesting fundamental question to investigate now is that of when the things we see and control emerge from the invisible quantum world.

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